Kalpa Publications in Computing
Volume 14, 2023, Pages 156–158
Proceedings of V XoveTIC Conference. XoveTIC 2022

Positioning system of Android smartphones through the physical properties of sound

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Abstract

Knowing the position of a device such as a smartphone accurately enough to control another device is a complex problem. Specific solutions (such as inertial measurement units) exist, but they are relatively expensive while do not provide accurate positioning over extended periods of time. In this project we explored methods based on the physical properties of sound to achieve quality positioning with affordable and relatively easy to set up equipment. Different options have been tested and we have chosen to use the Doppler effect to determine the speed of movement of the device and calculate its position in both 2D and 3D environments. Multiple tests have been performed demonstrating the advantages of the proposed method and pointing out the most important limitations. Finally, a demonstrator of the proposed technology has been developed to use a smartphone as a video game controller.

1 Introduction

The motivation of this project arises under the interesting concept of a system that would allow to control with a smartphone, any type of pointer or virtual element on a screen without requiring expensive technology (in addition, that is of very common possession). The idea is that anyone can interact easily and intuitively with the devices that require it. Unfortunately, it is currently not possible to use a smartphone to control a device in such a simple way. That is why this project aims to investigate methods that could help to make this concept a reality.

The objective of this project is the development of an Android smartphone positioning system based on one or more commonly used speakers. The principle of operation consists of emitting ultrasounds (not audible to humans) in such a way that, taking advantage of the Doppler effect, the relative movements of the mobile device with respect to the speakers can be measured.

An iterative development based on prototypes has been carried out, where in each iteration the dimensions of the positioning capability have been increased, adding new functionalities (filters, etc.) and exploring alternative methods to improve the accuracy.

This project is inspired by the work developed by Yun et al. (S. Yun, 2015), where a system capable of positioning mobile devices in two dimensions through the emission of ultrasound signals, using only common devices (speakers and smartphone) is presented. In this new project, other methods and techniques have been tested and their capabilities have been expanded.

2 Doppler effect based positioning

Positioning based on the Doppler effect means that a moving smartphone perceives a sound at a frequency different from that emitted. With the Doppler effect equation, the speed of the relative displacement between source and receiver (in our case the speakers, which are static) can be quantified. By determining this displacement repeatedly over time, at a sufficiently high update rate, the instantaneous velocity of the smartphone with respect to each speaker can be calculated. To increase robustness, different sound frequencies are used simultaneously, each having its own Doppler shift.

By integrating the velocity over time, the distance from the phone to each speaker can be known. Finally, using a trilateration algorithm, the position of the phone in space can be calculated. Figure 2 illustrates the operation of the system at various time instants.

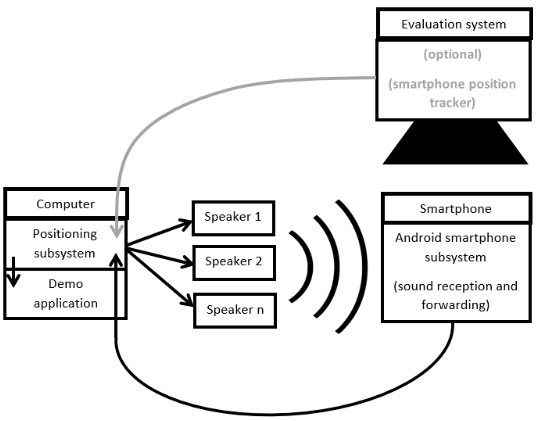

Figure 1: Architecture diagram

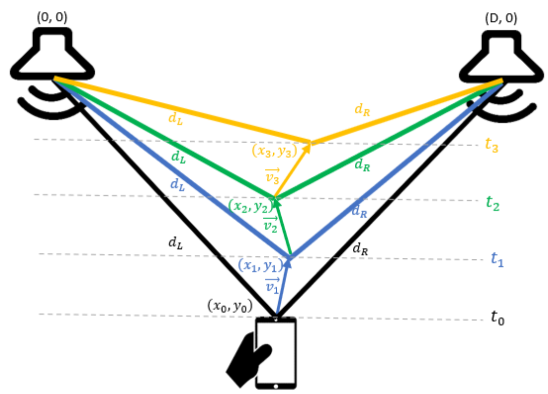

Figure 2: Positioning algorithm

The general architecture of the system (Figure 1) consists of a computer to which is connected an arbitrary number of loudspeakers (which emit the ultrasound) and the phone system itself, which is responsible for receiving and forwarding the sound to the computer for processing. Also shown is a camera that provides the ground truth of the position of the smartphone, which is only used for validation purposes (i.e., to measure the error committed by the system).

3 Results

The tests performed for the evaluation of the positioning system consisted of measuring the error between the position of the smartphone predicted by the developed system and the actual position measured by the camera of the evaluation system. It has been observed that the results obtained are largely dependent on the environmental conditions in which the system is being used.

It is worth noting the better quality of the results when testing in outdoor environments, due to the absence of surfaces that reflect the sound and hinder the accurate calculation of the real frequency displacement. In these tests, an average error of less than 5cm has been observed in several trajectories, each one with a duration of approximately 35 seconds. Figure 3 shows the mean error for each of the tests without and with noise minimization filters. The latter column group being the mean error of all tests.

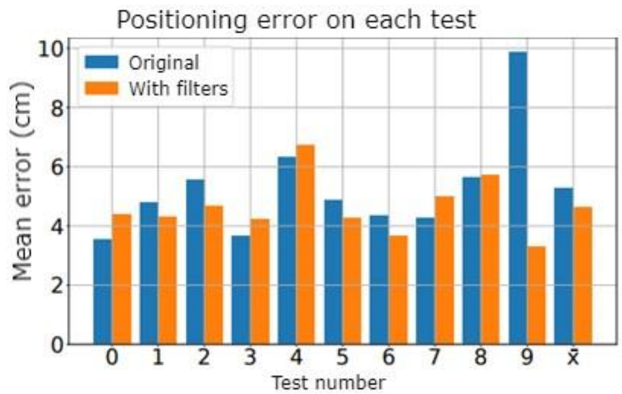

Figure 3: Positioning error on each test

4 Conclusions

It has been possible to develop a low-cost and easy to configure system capable of calculating the position of a smartphone with respect to a set of loudspeakers with high precision and for medium-long periods of time (close to one minute). In practical use, the accuracy could be maintained indefinitely over time by using additional information periodically. For example, by repositioning or placing the mobile device over a known or reference point.

The accuracy of the system depends on the environment, more specifically on objects and surfaces near the speakers that affect sound propagation. Typically, the accuracy is better outdoors. Properties of sound other than the Doppler effect have also been tested, but with worse results due to technical limitations (Somoza Domínguez & Vázquez Regueiro, 2022).

The system is scalable with the number of speakers and works in 3 dimensions. Multiple techniques have been tested to reduce the positioning error, and a demo app is provided, which apart from the position allows to control the orientation of a 3D racket model with the smartphone.

References

S. Yun, Y.-C. C. (2015). Turning a mobile device into a mouse in the air. *Proceedings of the 13th Annual International Conference on Mobile Systems, Applications, and Services*.

Somoza Domínguez, R., & Vázquez Regueiro, C. (2022). *Positioning system of Android smartphones through the physical properties of sound.* Retrieved from ruc.udc.es: https://ruc.udc.es/dspace/handle/2183/31274